Wind and Seismic Effects

Proceedings of the 30th Joint Meeting

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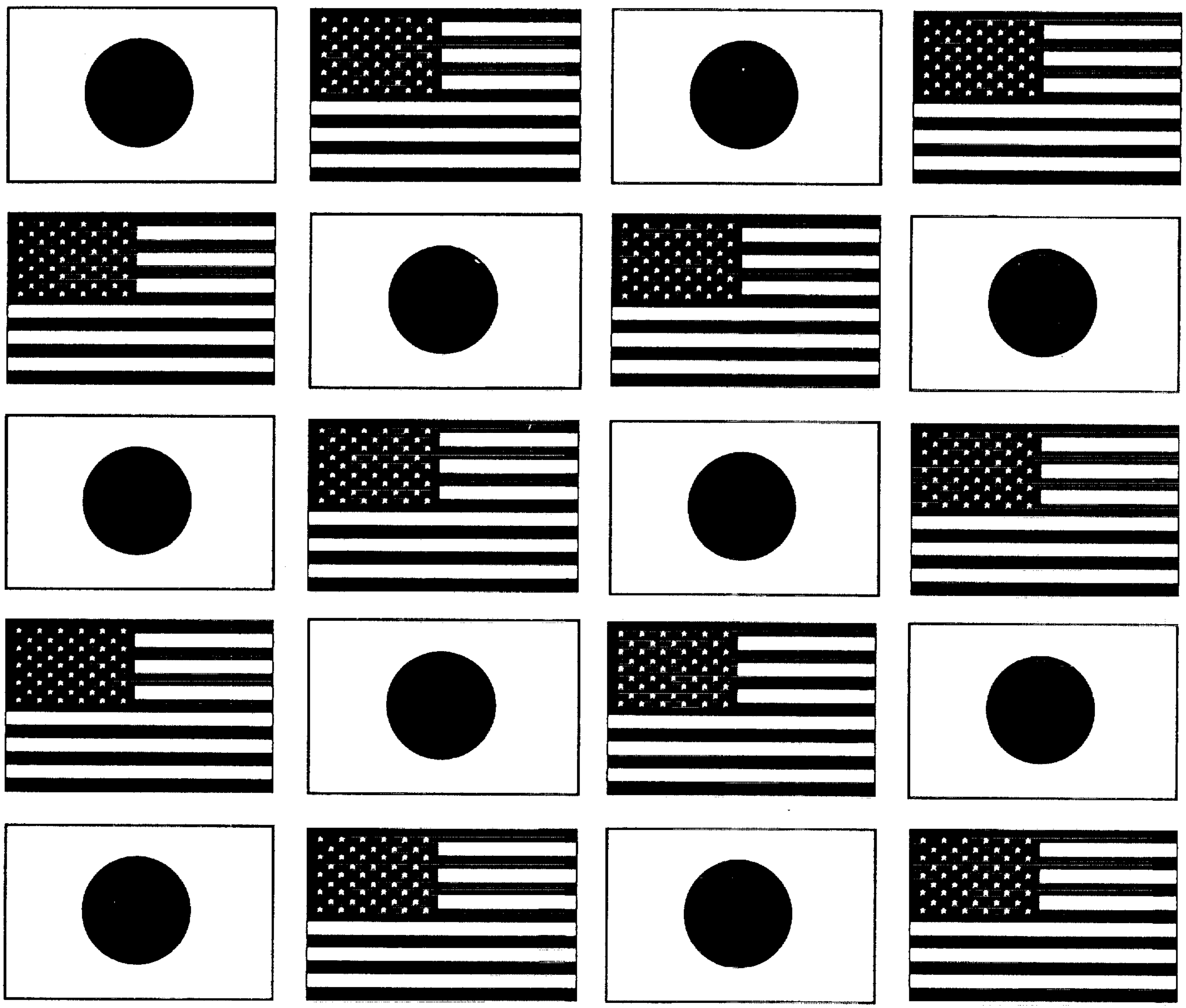

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Wind and Seismic Effects

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DEVELOPMENT OF PERFORMANCE-BASED BUILDING CODE IN JAPAN

- FRAMEWORK OF SEISMIC AND STRUCTURAL PROVISIONS -

By

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ABSTRACT

On February of 1996, it was officially announced by the Ministry of Construction that the Building Standard Law of Japan should be revised into that based on performance. The building code in Japan will be changed from current prescriptive type into performance-based type in a few years. In responding this announcement, the performance-based building code is now under development at the Building Research Institute (BRI).

In this paper, presented is the framework and concepts of the performance-based seismic and structural provisions in Japan proposed by BRI. In the principles of structural safety, the required performance and loads/forces levels are clearly defined. There are four routes in verification procedures and associated structural specifications following the principles of structural safety; proposed route, conventional route, small building route requiring no calculation, and other route including alternative verification procedures, deemed-to-satisfy provisions, and expert judgments. Seismic effects to buildings are considered on the basis of basic seismic design spectrum defined at the engineering bedrock under surface soil layers.

There are three levels in the objectives and requirements to building structures and loads/forces levels. The objectives are life safety, damage prevention, and continuous normal operation of a building. The principle of verification procedures is that the predicted response values should not exceed the estimated limit values.

The newly proposed verification procedure for major earthquakes is illustrated, as all others remain basically the same as those actually in use. There are indeed various analytical methods for predicting the response of structures subjected to earthquake excitations. The one which is shown here is based on the equivalent single-degree-of-freedom system and response spectrum method.

KEY WORDS: performance-based building code, seismic and structural provisions, required performance level, verification procedures.

1. INTRODUCTION

The need for the development of performance-based standards is a logical consequence of the rapid economic growth of Japan, which is strongly affected by the

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international economic progress.

In 1995, World Trade Organization (WTO) initiated first the idea of performance-based standards, which was concluded in the form of the Agreement on Technical Barriers to Trade (TBT). This agreement calls for an obedience will towards the guidelines and recommendations issued by the International Standards and International Standardization Institutions. Furthermore, International Organization for Standardization (ISO) is strongly promoting the revision of the current international standards on the basis of performance principles.

According to U.S.-Japan Framework Talks on Bilateral Trade, the American side has requested that the deregulation policy for restructuring the Japanese administration should be extended to the building industry as well, where the review of Building Standard Regulations and reduction of construction cost for housing are required.

Reflecting this developments, on February in 1996 it was officially announced by the Ministry of Construction authorities that the Building Standard Law of Japan should be revised on the basis of performance principles. Very recently, in the Building Council report of March 24, 1997, entitled "For a New Building Administration Framework, which could cope with the economic & social changes and their prospects in the 21st century", it was clearly stated that in order to compile a highly flexible New Building Standard Law, the current provisions must be revised into those based on performance. That served as a basis for the compilation of "Guidelines for the Performance-based Building Code".

2. PERFORMANCE-BASED BUILDING CODE

Unlike the in-current-use conventional Building Code, the Performance-Based Building Code prescribes clearly the type and the level of the required performance for a given building structure. In other words, for the precisely determined response of the structure subjected to assumed loads and forces, it prescribes the verification procedures to be used for the estimation of structure's conformity with the required structural safety.

However, even in the case of the performance-based provisions, the prescription of a minimum required level is necessary, being this the same as in the current Building Code Provisions. In this sense, the performance-based code is different form the performance-based design, which has been a current topic among structural engineers. The latter deals with a design procedure which is based on a clearly defined target performance for the structure considered, normally being prescribed higher than the minimum required performance level. Basically, the performance-based design is the structural design on the basis of consultation between the structural engineer and the owner of the building.

In this paper are presented the framework and the conception of the Performance-Based Structural Code, which is now under development at Building Research Institute (BRI) in Japan. The main aspects considered here are the conceptual framework of the Structural Code; the level and conception of the earthquake, wind, snow and live forces/loads; required structural performance against each forces/loads and the verification procedures to be used for the estimation of structure's conformity with the required performance level.

It should be noticed here that presented in this paper is just the state-of-the-art and up-to-now level of development of the Performance-Based Structural Provisions at BRI in Japan. It should not be considered as a fully completed version, ready to be presented for the final official approval.

3. CONCEPTUAL FRAMEWORK OF PERFORMANCE-BASED STRUCTURAL CODE

The conceptual framework of Performance-Based Structural Code proposed by BRI is shown in Fig. 1. Following the principles of structural safety, the verification procedures to be used for the estimation of structure's conformity with the required performance level are roughly classified as (see Fig. 1):

a. Proposed route
b. Conventional route
c. Small building route, and
d. Others

The proposed route represents a new verification procedure to be used instead of the current one, which is based on the calculation of allowable stress and estimation of ultimate capacity for lateral load. It considers the effects of major earthquakes as well as other forces and loads. The other effects which are not considered in the structural calculations, such as construction quality, durability, quality of construction materials, and nonstructural elements, are covered by structural specifications. In essence, by using this procedure it is possible to evaluate and verify the structural performance possessed by a designed structure, regardless of the design method used. It is just a verification procedure which verifies whether or not the prescribed performance objectives are met. Accordingly, for structural specifications as well the minimum required supplementary specifications are prescribed.

The second route represents the conventional verification procedure now in use, adopted as the standard structural calculation method. It can be supplemented with additional provisions in addition to those of the first route described above. However, if the principles of performance-based provisions are to be followed, it should be noticed that the obviously unnecessary parts to be considered by structural calculations are eliminated. To this extent, the second route can be considered as a kind of deemed-to-satisfy verification procedure.

The third route applies to small buildings. This route does not require structural calculations and is considered to be deemed-to-satisfy provisions. It prescribes only conventional-based structural specifications. Through this route, is attempted to make as clear as possible the details of each structural specification. In case of a possible structural calculation alternative, special clauses which allow for the implementation of newly developed materials, design methods and construction methods are provided.

In the fourth route are included all other alternative verification procedures and deemed-to-satisfy provisions, such as those developed and certified by private institutions as well as those requiring expert judgments.

The types of loads and forces considered in the newly proposed verification procedure remain almost the same with those currently in use. However, for the case of earthquake effects only, new earthquake motion provisions are prepared to replace the current earthquake force provisions.

In a definite proposal, the earthquake motion response spectra at the engineering bedrock, assumed to be the stratum having shear wave velocity in the range of several hundreds m/s, is considered as the basic design spectra. On the basis of this conception for the earthquake input motion, it is possible that earthquake effects be not only accounted rationally through the incorporation of influence of local soil conditions on ground motion characteristics at the free surface but also conveniently incorporated in the newly developed design procedures of seismically isolated and response controlled structures. Furthermore, it is anticipated that the future proposals expected for the verification and design procedures be suitably implemented.

4. REQUIRED PERFORMANCE LEVEL FOR BUILDING STRUCTURES

An outline of requirements for building structures and loads/forces levels is shown in Table 1. In the vertical column on the left hand side of the table are shown the requirements for building structures, while in the rest of the table are shown the main types of loads/forces to be considered and their corresponding levels for each of the requirements assigned for building structures. Undoubtedly, the loads/forces shown in Table 1 are to be combined according to specified rules.

As it is shown in Table 1, requirements for building structures are classified in three categories, which are explained below.

4.1 Life Safety

The essential purpose of this requirement is the safety of life. It should be expected that under the action of loads/forces taken into consideration, the building should not experience any story collapse. In other words, it is required that the situation of not providing sufficient space for possible survival of building occupants should not be experienced.

4.2 Damage Prevention

The aim of this requirement is damage prevention. Under this provision, it is required first that after the action of the loads/forces taken into consideration, no structural damage which could threaten the structural safety of the building will take place. Furthermore, it is required that no other kind of damage which causes in the building structure a situation which does not comply with other requirements of the Building Standard Law should be experienced. The above mentioned requirement for no structural damage which could threaten the safety of the structure means that the structural safety performance required by Section 4.1 should be preserved. The second requirement related to other kind of damage means that the provisions of Building Standard Law concerning fire safety should be satisfied. It should be mentioned here that, the requirements for Damage Prevention described in this section are included in the Life Safety requirements as well.

4.3 Continuous Normal Operation

The purpose of this requirement is the assurance of continuous normal operation of the building structure. It aims at avoiding the harmful deformations and vibrations in structural frames, members, interior and exterior finishing materials of the building structure while subjected to loads/forces taken into account. The above mentioned harmful deformations and vibrations are assumed to be those related to dead, live and snow loads acting for a relatively long time on the structure causing thus excessive deformations in slabs and beams, and consequently discomfort to the occupants or difficulties in the operation of the building. The details for the requirements concerning the discomfort to the occupants or difficulties in the operation are not yet clearly formulated. Therefore a further investigation is necessary. It should be mentioned here again that, the requirements for Continuous Normal Operation described in this section are included in the Life Safety requirements and Damage Prevention requirements as well.

For each of the three categories of requirements for building structures described above are assumed the following levels of loads/forces:

4.4 Maximum Probable Event Level

This level of loads/forces corresponds to the category of requirements in Section 4.1 for building structures and is assumed to produce the maximum possible effects on the structural safety of a building to be constructed at a given site. The maximum possible earthquake motion level is determined on the basis of historical earthquake data, recorded strong ground motions in the past, seismic and geologic tectonic structures, active faults, and others. This earthquake motion level corresponds nearly to that of highest earthquake forces used in the current seismic design practice, representing the horizontal earthquake forces induced in the building structures in case of major seismic events. Wind forces and snow loads are determined on the basis of a

100-500 year return period. This level is somewhat higher than the current one used in the actual design practice.

4.5 Once-in-a-Lifetime Event Level

This level of loads/forces corresponds to the category of requirements in Section 4.2 for building structures and is assumed to be experienced more than once during the lifetime of the building. Strictly speaking, earthquake, wind and snow are natural phenomena with different probability of occurrence and normally for each of them should be assumed different return period. Therefore a return period interval of 30-50 years is supposed to cover all these three natural events. This level of earthquake motion corresponds nearly to the middle level earthquake forces used in the current seismic design practice, representing the horizontal earthquake forces induced in the building structures in case of moderate earthquakes. The levels of wind forces and snow loads are nearly the same with those being actually used in the current design practice.

4.6 Ordinary Event Level

This level of loads/forces corresponds to the category of requirements in Section 4.3 for building structures and is normally assumed to be experienced several times during the lifetime of the building. For the case of snow loads it is roughly assumed a return period of 3-5 years. This level is not clearly prescribed even in the current provisions. Therefore a further careful investigation is needed for it.

Finally, the way the live loads will be treated in accordance with building structures requirements is still under investigation. Because of its totally different character compared to earthquake, wind and snow loads/forces, known as natural phenomena of temporary effects, it is considered that the live loads could be better prescribed through two separate options: extraordinary and ordinary options.

5. VERIFICATION PROCEDURES FOR A REQUIRED PERFORMANCE LEVEL

Various response and limit values are considered for use in proposed verification procedures, in accordance with each of the requirements prescribed for building structures. A representative example of this arrangement is shown in Table 2. The principle of verification procedures is that the predicted response values due to the action of forces/loads on building structures should not exceed the estimated limit values. Fundamentals of proposed verification procedures corresponding to each level of earthquake, wind and snow loads/forces are described below.

5.1 Verification Procedures Corresponding to Maximum Probable Event Level

In case of earthquakes, the maximum displacement response of the building structure subjected to strong ground motions should be smaller than the displacement limit. While in case of wind and snow, it is required that the maximum stresses developed in the structure should be smaller than the stress limits. In defining displacement and stress limits for earthquake motion and wind forces respectively, it may be necessary to consider the effects of repeating cycles in the plastic region of the response as well. However, fixing some stress limit values for the case of wind forces is very difficult at the moment, because the actual design of building structures against wind forces in general do not account yet for the inelastic behavior. Concerning the analytical methods to be used for predicting structural response, it is noted that they should not be necessarily the same as the current ones. Accordingly, in the newly proposed verification procedures, it is expected that analytical methods to be used for the case of earthquake excitations and that of wind/snow forces/loads be different. In the former case it is expected to apply Equivalent Single Degree of Freedom System and Response Spectrum Method, while in the latter one Static Elasto-Plastic Analysis.

5.2 Verification Procedures Corresponding to Once-in-a-Lifetime Event Level

For this level of earthquake, wind and snow loads/forces it is required to be confirmed whether the stresses taking place at each structural element satisfy the condition of being smaller than the limit stress. The limit stress mentioned here implies that the whole structure behaves generally within the elastic range. In case of snow loads, it is additionally required that the creep effect be taken into account in defining limit stress values. In any case, the fundamental conceptions of the current and newly proposed verification procedures are not much different. Therefore, it is expected that the actual static elastic analysis be of further use.

5.3 Verification Procedures Corresponding to Ordinary Event Level

Actually, the verification for this level of loads/forces is not definitely required. Only in case of special need or situation, the necessary performance is examined in the current design process. Displacement, stress and acceleration limit values are used in the verification procedures of this level. Defining these limit values seems to be a rather difficult issue which indispensably needs a careful investigation.

The verification procedures for live loads are expected to be almost the same as those being used in the current practice. Moreover, from Table 2 it can be noticed that no description on foundations and soils are given. This subject is also under investigation.

Besides the limit values defined on the basis of the requirements for building structures as it is shown in Table 2, other displacement-, stress- or acceleration-related limit values, defined on the basis of the requirements for architectural, mechanical and electrical elements permanently attached to buildings, are considered in certain cases if necessary. On this point, a special investigation is needed.

As it was mentioned above, excluding the newly proposed verification procedure for maximum probable earthquake events, all others remain basically the same as those actually in use. Therefore, hereafter the focus is put on the proposed verification procedure for the case of earthquake excitations. A flow chart of this procedure is illustrated in Fig. 2. There are indeed various analytical methods for predicting the response of structures subjected to earthquake excitations. The one which is shown here is based on the equivalent single-degree-of-freedom system and response spectrum method.

5.4 Proposed Verification Procedure for the Case of Major Earthquakes

According to this procedure the steps to be followed are:

I. Determine the limit displacement of the structure.

II. Determine the hysteretic characteristic, equivalent stiffness and equivalent damping ratio of the structure.

  i) Model the structure as a simplified equivalent single-degree-of-freedom system (ESDOFS) and establish its force-displacement curve (see Fig. 2a).
  ii) Assume now that the limit displacement determined in step I corresponds to the above mentioned ESDOFS.
  iii) Determine the equivalent stiffness in accordance with the limit displacement.
  iv) Determine the equivalent damping ratio on the basis of viscous damping ratio, hysteretic dissipation energy and elastic strain energy of the structure (see Fig. 2b).

III. Determine the response spectra to be used in the verification procedure.

  i) For a given basic design spectrum at the engineering bedrock level, draw up the free-field site-dependent acceleration (Sa) and displacement response spectra (Sd), for different damping levels.

ii) In the estimation of free-field site-dependent acceleration and displacement response (step i) above), consider the strain-dependent soil deposit characteristics.

iii) In case of need, present graphically the relation of Sa-Sd, for different damping levels.

IV. Examine the safety of the structure.
In this final step, it is verified whether the response values predicted on the basis of the response spectra determined according to the step III satisfy the condition of being smaller than the limit values estimated on the basis of step II (see Fig. 2c).

The verification procedure presented above is in essence a blend of equivalent single-degree-of-freedom modeling of structures with the site-dependent response spectrum concept, which makes possible the prediction of maximum structural response in case of major earthquakes as well as the confirmation whether the predicted response values are smaller than the limit ones. Moreover, it is also noted that the soil-structure interaction effects should basically be considered. The factor of structural characteristics Ds, used in the current practice for verifying the ultimate capacity of the structure to resist lateral loads, is determined on the basis of the concept that the structural strength necessary to keep the displacement response during earthquakes smaller than the limit displacement, estimated on the basis of plastic deformation capacity of the structural members, should be guaranteed.

From the above discussion, it can be concluded that the newly proposed verification procedure is just the process to estimate the Ds values. The difference lies on the fact that the proposed procedure does not go up to the calculation of the Ds values. It ends just before this step.

In order to determine the limit displacement of the structure, a specific displaced mode is necessary to be assumed in advance for its inelastic response (see Fig. 2a). Basically, any predominant or possible to be experienced displaced mode of the structure subjected to earthquake forces can be applied. The predominant or possible to be experienced displaced mode implies any of the failure modes observed during the major earthquakes such as beam failure mode, story failure mode or any other definite failure mode. Furthermore, precisely determined characteristics of structural materials should also be provided.

In the illustration presented above for the proposed verification procedure the limit value referred to is the maximum displacement. Nevertheless, besides displacement any other measures can be used, for example energy. In this case, both the response and limit values should be expressed in terms of energy.

The application of the proposed verification procedure for building structures where torsional vibration effects are predominant requires a further detailed investigation.

Finally, a more appropriate consideration of the loading duration time and material properties in the current verification procedure based on the allowable stress concept is under investigation.

6. FUTURE SCOPE

Having established the fundamental principles for the revision of the current Building Standard Law of Japan does not mean that everything is done. The framework and concepts of performance-based building provisions presented in this paper constitute just the beginning of an enormous task to be done in the future. In order to realize the intentions of performance-based standards, directed towards the expansion of free initiative, the promotion of new technologies, and the activation of market competition, as well as the verification of the designed performance level in constructed building structures, the establishment of building related institutions is needed. For this purpose, The Building

Council is appealing for the openness of private institutions towards building verification procedures and inspection. Expanding the role of private institutions in the verification/inspection system is also a very important condition for the implementation of performance-based provisions. Consequently, for a successful operation of this verification/inspection system, high level of competence, organizing ability and responsibility are required.

Furthermore, the emphasis should not be given only to the performance-based provisions. In order to widen the use of recently emerged performance-based design, it is necessary to further intensify the efforts towards a marketable performance. In this sense, the popularization of performance indication system proposals is desired.

7. CONCLUDING REMARKS

In this paper, presented is the state of the art of the Performance-Based Building Code of Japan, currently under development at the Building Research Institute. In essence, performance-based provisions intend to provide as clearly as possible answers to the frequently raised questions: for what purpose, towards what objective, and for what conditions. The greatest advantage of this new approach lies on the fact that it focuses primarily on the achievement of the prescribed objectives, regardless of the methodology used. As a result, while promoting technical development, it may become possible some time in the future that the owner himself to select the desired performance of the building. On the other hand, due to the long time and high cost required for its implementation, it may happen that the performance-based approach results in a complicated verification procedure, pointing out thus the need for a much more careful judgment in selecting between specification-based or performance-based provisions. There are still many issues to be considered in the future and in dealing with them it should be kept always in mind the purpose that the performance-based concept is to be applied.

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Table 1 Requirements for Building Structures and Loads/Forces Levels

<table>
<tr><th>Load & Force
Requirement</th><th>Earthquake</th><th>Wind</th><th>Snow</th><th colspan="2">Live</th></tr>
<tr><td>(a) Life Safety
(to prevent failure of stories in structural frames)</td><td>Probable Maximum Earthquake
(earthq. records, seismic and geologic tectonic structures, active faults, etc.)</td><td colspan="2">Probable Maximum Event
(return period: 100-500 years)</td><td rowspan="2">Extraor-
dinary</td><td rowspan="3">Ordinary</td></tr>
<tr><td>(b) Damage Prevention
(to prevent damage to structural frames, members, interior and exterior finishing materials in order to avoid the conditions not satisfying the requirement (a) and others)</td><td colspan="3">Once-in-a-Lifetime Event
(return period: 30-50 years)</td></tr>
<tr><td>(c) Continuous Normal Operation
(to eliminate harmful deformation or vibration on structural frames, members, interior and exterior finishing materials, equipment and foundation deteriorating functions)</td><td colspan="2"></td><td>Ordinary Event
(return period: 3-5 years)</td><td></td></tr>
</table>

Note: The deterioration of materials during the life time of a structure should be considered.

Table 2 A Representative Illustration of Proposed Verification Procedures

Requirement \ Load/Force		Earthquake	Wind	Snow	Live	
a) Life Safety	Level	Maximum Probable Earthquake	Maximum Probable Event (Return Period 100 - 500 years)		Extraordinary	Ordinary
	Response Value	Maximum Displacement	Maximum Stress	Maximum Stress	Maximum Stress	
	Limit Value	Limit Displacement[*1]	Limit Stress[*1]	Limit Stress[*2]	Limit Stress[*2]	
b) Damage Prevention	Level	Once-in-a-life-time-Event (Return period 30 - 50 years)			Extraordinary	Ordinary
	Response Value	Stresses taking place at each structural element			Stresses taking place at each structural element	
	Limit Value	Limit Stress[*3]		Limit Stress[*4]	Limit Stress[*4]	
c) Continuous Normal Operation	Level			Ordinary Event Level (Return Period 3 - 5 yrs)		Ordinary
	Response Value			Stress and Displacement at required elements only	Stress and Displacement at required elements only	
	Limit Value			Limit Stress and Displacement[*5]	Limit Stress and Displacement[*5]	

*1 - Repeating cycles effect at plastic region of response to be taken into account.
*2 - Creep effect to be taken into account.
*3 - The whole building structure behaves roughly within elastic range.
*4 - The whole building structure behaves roughly within elastic range and creep effect to be taken into account.
*5 - Stresses should be less than the elastic limit and creep effect to be taken into account.

Notes :

1) The limit values corresponding to Maximum Probable Event Level are determined based on the condition that equilibrium of forces and displacement compatibility in the structural system are guaranteed.
2) Displacement and acceleration related limit values, determined on the basis of the requirements for architectural, mechanical and electrical elements permanently attached to building structures, are thought to be considered in certain cases.

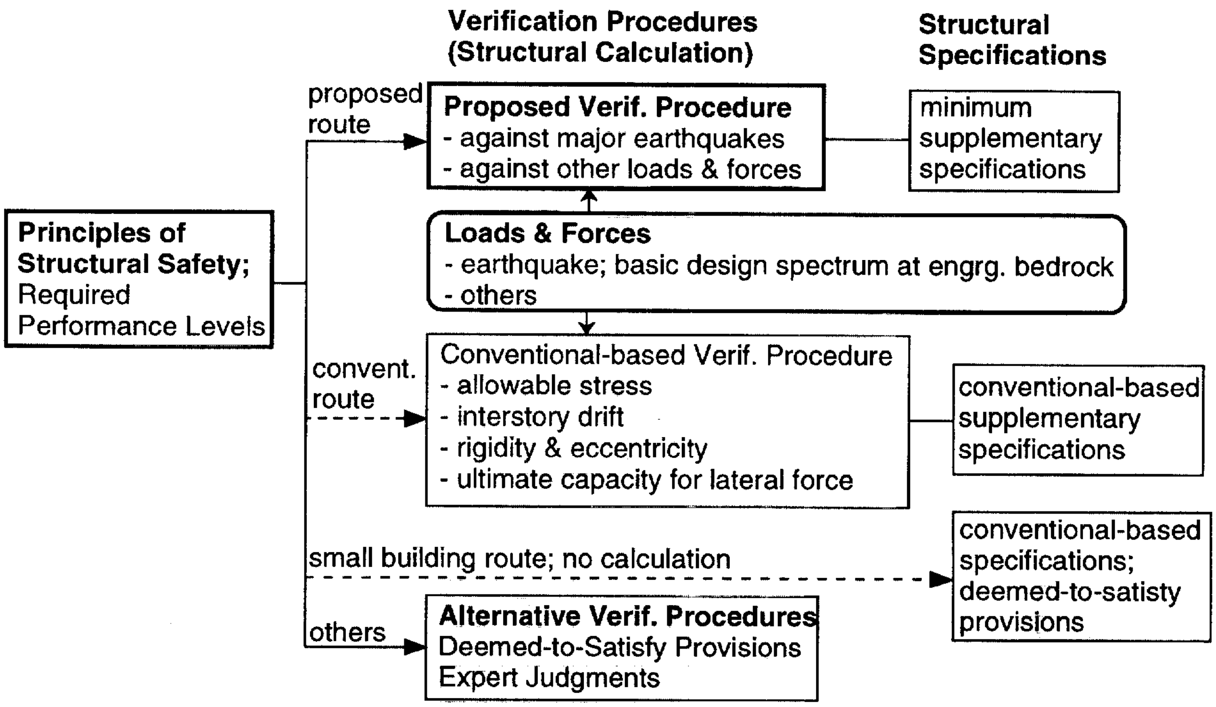
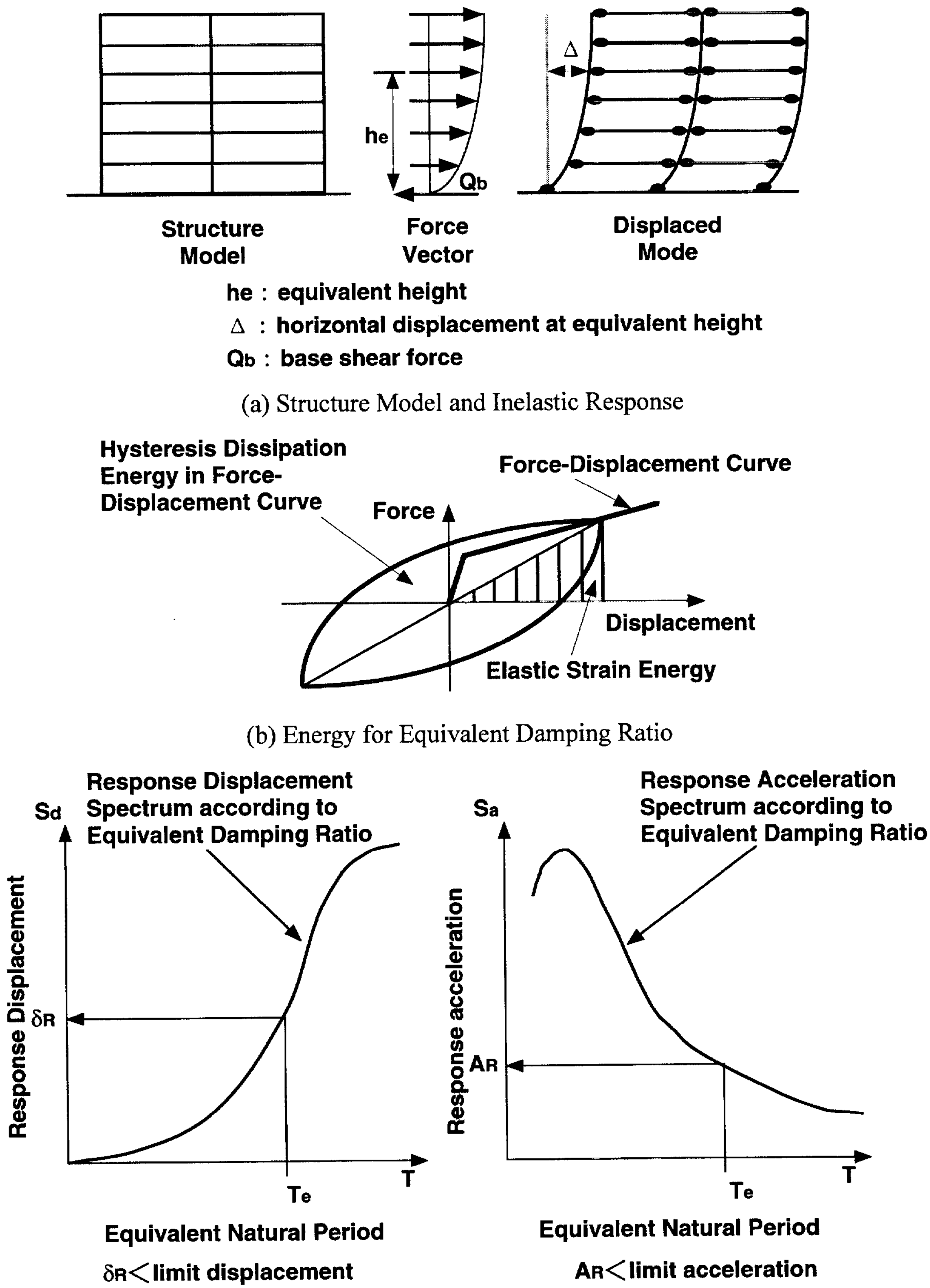


Fig. 1 Conceptual Framework of Proposed Performance-Based Structural Provisions



(a) Structure Model and Inelastic Response

(b) Energy for Equivalent Damping Ratio

(c) Comparison of Expected Response Values and Estimated Limit Values

Fig. 2 An Illustration of Proposed Verification Procedure for Major Seismic Events